DAVID EDWARD HUGHES, F.R.S., 1831–1900

By G. Burniston Brown

[*Plates* 10 *and* 11]

DAVID EDWARD HUGHES (F.R.S. 1880, Royal Medallist 1885 and Benefactor commemorated by the Hughes Medal) was born at Green-y-Ddwyryd, near Corwen, North Wales on 16 May 1831. His grandfather had been a bootmaker in Bala and his father, David Hughes, continued his business but later moved to London. When Hughes was seven the family emigrated to the U.S.A. and settled in Virginia where he received his education. From his father he inherited a very delicate musical ear which was to prove of great value to him in his later experimental work. He also possessed a gift for improvizing tunes and this drew the attention of a German pianist, well-known at the time, who was sufficiently impressed to obtain for him, at the age of nineteen, the professorship of mucic in St Joseph's College, Bardstown, Kentucky.

Along with his musical activities he also developed a love of making mechanical and electrical experiments. After a year, he was offered the Chair of Natural Philosophy, and so he gave lectures in physics as well as music. His experiments grew until they absorbed so much of his interest that in order to devote more time to them and avoid teaching duties, he resigned and moved to Bowling Green, Kentucky, where he taught music to private pupils only, spending his spare time in experiments with simple apparatus that he constructed himself.

During one of his periods of musical composing the idea came to him of improvements that could be made to the printing telegraph then in its early development. These improvements were so successful that in 1854 he was able to go to Louisville, Kentucky to superintend the construction of his new instrument. One of the advances that he made in order to synchronize the transmitter and receiver was the substitution of circularly vibrating springs for the tuning forks then used. Needless to say, the keys took the form of a piano keyboard. The new instrument was patented in the following year and adopted by the New York Associated Press and later by the Western Union Telegraph Co. After this auspicious start Hughes came to England in 1857. However, no favourable reaction occurred, but when he went over to Paris, he started a triumphal series of successes which led to a galaxy of titles and a

large fortune. The Emperor Louis Napoleon received him, and later he became a Commander of the Imperial Order of the Legion of Honour; when Russia adopted his teleprinter he was a guest of the Czar who gave him the Order of St Anne; the Emperor of Austria gave him the title of Baron and the Order of the Iron Crown; in Turkey he received the Grand Cross of the Order of Madjidieh from the Sultan; more followed until he had been recognized in almost every civilized country but his own.

When, therefore, he returned to London in 1875 he was able to complete the object he had in mind when he moved to Bowling Green—to give his whole time to experiments in physics. In his rooms at 94 Great Portland Street he then commenced examining various electrical phenomena with the help of Graham Bell's invention of the speaking telephone, which besides rendering human speech transmissible along wires, was also a very sensitive detector of changes in electrical currents. It worked on known electromagnetic principles so that it was easy to reproduce, and Hughes was one of the first to construct one and make use of it. He made a very large number of experiments of various kinds because he was working in an unexplored and unknown field and had had no training in the subject. He was forced, therefore, into taking the first step in the application of scientific method to such a case—by 'varying the circumstances'. In his first paper read before the Royal Society on 9 May 1878 (1), he describes how the knowledge that the electrical resistance of selenium was affected by light caused him to wonder whether sounds would have a similar effect, since Sir William Thomson (Lord Kelvin) and others had shown that physical strains in wires altered their resistance and 'sonorous vibrations' would obviously produce rapid variations in strain at different points of the wire.

Hughes goes out of his way to emphasize that 'no apparatus of any kind constructed by a scientific instrument maker was employed'. In this case the circuit consisted of three Daniell cells 'made by using three common tumblers . . .' joined to a telephone and the circuit completed by the connexion of any strained conductor that might be examined. Hughes introduced a strained wire and 'listened attentively with the telephone to detect any change that might occur when the wire was spoken to or set into transverse vibration by being plucked aside'. Nothing was heard until the wire broke, when a momentary 'peculiar rush or sound was heard'. He then tried 'to imitate the condition of the wire at the moment of rupture' by pressing the broken ends together with varying degrees of pressure. More experiments showed that any part of a conductor would serve to reproduce sounds 'provided one or more portions of it were separated and only brought into contact by a slight but con-

DAVID EDWARD HUGHES, F.R.S. (1831–1900)
From a photograph in the Royal Society Library

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Plate 11

94 Great Portland Street, London, W1

In this corner house (with Langham Street), David Hughes lived and experimented. In the years 1877–1879 the microphone was invented, and wireless spark signals transmitted and received for the first time.

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stant pressure. Thus if the ends of the wire terminate in two common nails laid side by side, and separated from each other by a slight space, were electrically connected by laying between [across] a similar nail, sound could be reproduced. The effect was improved by building up the nails log-hut fashion, into a square configuration using ten or twenty nails. A piece of steel acted well'.

However, the timbre of the voice was not well reproduced, and after many more experiments Hughes found that the carbon in the form of willow charcoal, if it was 'metallized' by being heated to white heat and plunged into mercury, was much improved in sensitivity, due to pores in the charcoal being filled up with minute globules of mercury. Pine charcoal, when heated in an iron vessel, containing 'a free portion of tin, zinc, or other easily vaporized metal' made a 'most excellent material for the purpose' and clearly reproduced human speech. Hughes had therefore discovered what we now call the *multiple-contact microphone*, although he himself called his many varieties 'transmitters' when they were in a glass tube or bottle. The word microphone he used for the simplest form of contact such as that in his lozenge-shaped metallized gas carbon microphone, which was one inch long, a quarter of an inch wide at the centre and one-eighth of an inch in thickness. This was stood up vertically between two horizontal carbon blocks, the lower pointed end of the lozenge acted as a pivot, and the top, made round, 'plays free in a hole' in the upper block (see Figure 2). The contact of the lozenge at the top was therefore very feeble, depending on its own weight acting at the very small angle with the vertical that it was permitted by the hole. Hughes comments that the best form of instrument has yet to be found, but the carbon lozenge would easily detect the noise made by a fly walking 'with a peculiar tramp of its own' confined under a glass tumbler along with the microphone on a matchbox.

As soon as this paper appeared Evershed tells us that he himself repeated successfully all the experiments described (even the one concerned with the footsteps of the fly) with the help of the Hughes's three-nail microphone, exclaiming 'What are we to think of the imagination of a man who sets out with the aid of three small nails to hear a fly walking?' (2). Sir Oliver Lodge, who was experimenting with Hughes's Induction Balance using 'numerous coils which happened to be accessible in University College Laboratory', did not have the same success at repetition: he was forced to imitate Hughes's arrangements and dimensions more exactly. He was then able to confirm his results, and expressed his increased admiration for Hughes's delicate constructional and experimental skill (3). Other forms of microphone were extremely sensitive to small quantities of electric charge. A metal filing stuck

on a piece of sealing wax and charged by contact with a Leyden jar caused a sound in the telephone when it touched the microphone although it was undetectable by a gold-leaf electroscope or quandrant electrometer.

When he read his second paper to the Royal Society (4) Hughes described and demonstrated his new induction balance and sonometer. Here again he used words that now have a different meaning, his 'sonometer' being 'an absolute sound measurer: a later invention of my own'. These two devices are shown connected together in Figure 1. At the top left corner is shown Hughes's simple method of producing regularly interrupted current in the primary circuits of the coils: *C* is a clock whose ticking is picked up by the microphone lozenge shown (not very clearly) attached to the clock stand and close to its face. The Daniell cells *B* supplied the current. The induction balance consists of two pairs of coils, each coil being made by winding 100 metres of No. 32 silk-covered copper wire on box-wood spools. The first pair is shown on the vertical holder in the centre of the picture separated by a fixed distance of 5mm. The second pair is in the framework on the right (S_2), designed to enable their separation to be varied and measured by a micrometer arrangement. The

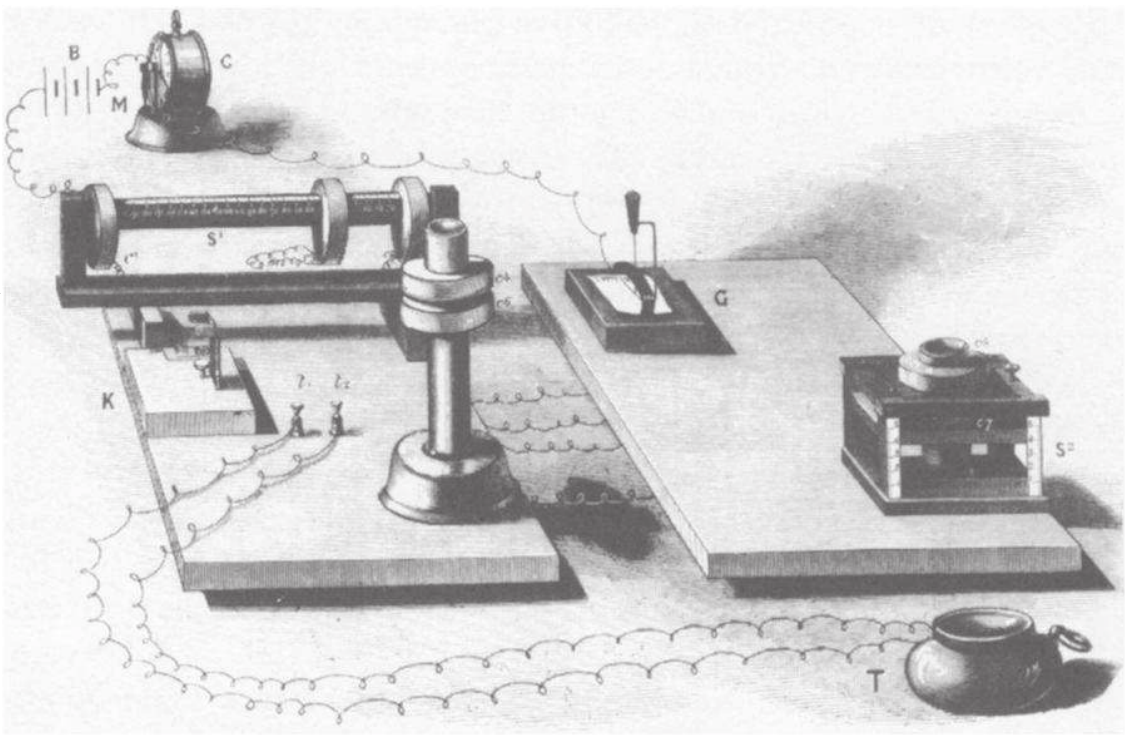

FIGURE 1. The Induction Balance and Sonometer
From *The Telegraphic Journal*, Vol. 7, p. 180, June 1879

C Clock
M Microphone
B Battery
K Switch
S^1 Sonometer
S^2 Induction Balance
(together with coils on the central column)
T Telephone

two pairs are connected so as to oppose one another so that when the separation of the second pair is 5mm there is no sound in the telephone. Changes in their induction, produced, say, by placing various materials in one of the coils in the first pair can thus be given a measure.

The sonometer (upper left at *S*) consists of two fixed primary coils 40cm apart, and a secondary coil connected to the telephone *T* that can be moved along a graduated bar. The fixed coil at the left contains 100m of wire and that on the right only 6m. The balance point of zero sound is thus shifted to the right allowing a longer scale. The moving coil is moved along the scale until the out of balance noise in the telephone is just audible: a reading on this scale then gives a measure of acuity of hearing. This instrument was of sufficient sensitivity to interest medical workers searching for some measure of hearing ability (5).

Hughes used the sonometer with the induction balance to examine the properties of metals and alloys. If a piece of metal, such as a shilling, is placed in one of its coils the induction balance is disturbed and a noise heard on the telephone. He managed, by switching the telephone quickly with the key *K* to the sonometer circuit, to move its sliding coil until the sound appeared to his ear to be the same as that which had been produced by the coin. This technique was later much improved by a null method (zero sound) resulting in very great sensitivity in distinguishing different metals and detecting the amounts of them in alloys. One part of alloy in 10 000 parts of basic metal was easily shown—a sensitivity far exceeding any chemical process known at the time (6). It is reported to have been ordered for the Mint. It was also successful in finding the bullet in the body of the assassinated American President, James Garfield, who was shot in a Washington railway station by a disappointed office seeker in 1881. A solemn description, complete with a diagram entitled 'The Localization of the Bullet in President Garfield's Body', will be found in the *Telegraphic Journal* for 15 August 1881. Movement of the pair of coils on one side of the balance enabled the maximum noise in the telephone to be found. This was when it was nearest to the bullet. The depth inside of the bullet was found by simply bringing another similar bullet to the other pair of coils and measuring its distance when the noise was balanced out. The position of the bullets is illustrated but the President is not shown (7).

Hughes naturally felt that by the invention of these instruments he had fulfilled a hope that he had expressed in the beginning of his second Royal Society paper, namely to 'again attempt to investigate the molecular construction of metals and alloys'.

Early in 1879 Hughes was making experiments with his induction balance

when he was troubled sometimes by a clicking noise in the telephone that prevented him from getting the coils balanced. This he traced to a loose connexion in the secondary circuit, and this noise continued when a microphone was substituted for it. More experiments showed that this 'extra current', as he called it, was not due to ordinary induction but directly due to the spark at the interrupter when the current was made and broken. This effect was new to him, so he set to work to examine it with his usual self-made simple apparatus. John Munro, who was present at some of these investigations, describes his apparatus as consisting of 'sewing needles, bits of cork, wood and carbon, odds and ends of wire, pomade bottles, penny boxes purchased at a dentist's and presumably for holding false teeth, not forgetting of course, the indispensable red sealing wax to stick the parts together. I am afraid that a dealer in old curiosities would scarcely give the entire collection house room' (8). This last remark well describes feelings that one has today when viewing what remains to be seen in the Science Museum (9).

At first his 'transmitter' was a single cell joined to a clockwork interrupter and one of his primary coils. A wire several feet in length connected the primary to the secondary 'receiver' which consisted only of a telephone in circuit with a lozenge microphone. The 'extra spark' of the interrupter was clearly heard in the 'phone. In later experiments between 15 and 24 October 1879, Hughes, having found that he could abandon the coil, was encouraged to disconnect the transmitter and receiver, which were in different rooms, so that

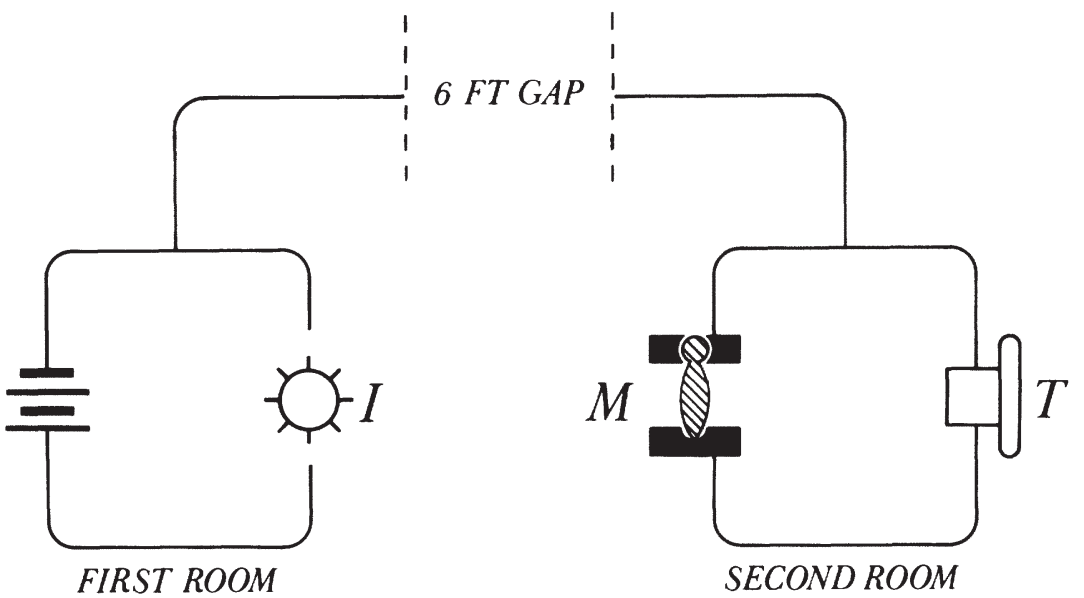

FIGURE 2. The first wireless receiving circuit

I Clockwork interrupter
M Metallized carbon lozenge microphone
T Telephone

there was a gap of about six feet in the connecting wire. The signals were still audible—in what became, in fact, the first wireless receiving circuit (Figure 2). He later discovered that joining both the transmitter and the receiver to earth by means of the gas pipes improved the reception. This led him to try to make the earth part of the receiving circuit by joining the telephone to a gas pipe of lead and the microphone to a water pipe of iron. This greatly improved the performance, and he traced this to be due to the different metals making a feeble 'earth battery'. The incoming signals appeared to affect the microphone so that it varied the feeble and constant earth current. This suggested to him that he should put a battery in the receiver circuit, and when this was done, he found that 1/50th of a volt would suffice to make it extremely sensitive. He also tried improving the transmitter by attaching an iron fender to the interrupter to see if it helped the spreading of the signals, and later changed it for wires held up by being stiffened with laths. He had thus invented the earth-connected transmitting aerial (10).

Hughes had now discovered the principal circuit components for successful wireless telegraphy. He proceeded to extend the 'gap' by sending and receiving signals from different parts of his house and then tried to reach the public baths in Tottenham Court Road ('about ½ mile') but the water noise prevented detection. Then leaving his transmitter at his home, he walked up and down Great Portland Street holding the microphone in one hand and the telephone to his ear with the other. The clicking noises made by the transmitter were audible for over a quarter of a mile, and he noticed that the signals faded opposite certain buildings and increased near others. But he records with disappointment that when he tried to reach Mr Grove's house in Bolsover Street, 500 yards away, 'there was not the slightest trace of sound . . . Thus the current does not travel any great distance' so he 'saw no hopes of its usefulness' (11).

In December 1879 Hughes invited some members of the Royal Society including Sir William Crookes and Mr Preece, Electrician to the Post Office, and some friends to witness his experiments. They were much impressed, so that before writing a paper for the Society, he invited the President and the two Secretaries, Professor Huxley and Sir George Stokes, to his house. This was a most unfortunate move on his part and he describes its results sadly in one of his notebooks as follows (12):

> February 20th 1880. Mr Spottiswoode, President of the Royal Society, Prof. Stokes and Prof. Huxley, visited me today at half-past 3 p.m. and remained until a quarter to 6 p.m., in order to witness my experiments with

the Extra Current Thermopile etc. [13] The experiments were quite successful, and at first they were astonished at the results, but at 5 p.m. Prof. Stokes commenced maintaining that the results were not due to conduction but induction and that results then were not so remarkable, as he could imagine rapid changes of electric tension by induction. Although I showed several experiments which pointed conclusively to its being conduction, he would not listen, but rather pooh-poohed all the results from that moment. This unpleasant discussion was then kept up by him, the others following his suit, until they hardly paid any attention to the experiments, even to the one working through gas-pipe in Portland Street to Langham Place on roof. They did not sincerely compliment me at the end on results, seeming all to being very much displeased, because I would not give at once my Thermopile to the Royal Society so that others could make their results. I told them that when Prof. Hughes made an instrument of research, it was for Prof. Hughes researches and no one else. They left very coldly and with none of the enthusiasm with which they commenced the experiments. I am sorry at these results of so much labour, but cannot help it.

Signed D. E. Hughes

February 21st. I wrote to Mr Spottiswoode that my opinion, firmly based on true experiments, that it was conduction and nothing else; so I have made matters worse, and may expect nothing else from them, except that they will probably copy my apparatus and make their own experiments.

Adieu.

Thus saying good-bye to the results of long hours spent on what he thought were new and remarkable discoveries, Hughes was disheartened, dropped his idea of writing a paper, and all but abandoned his research. He had made several tests to assure himself that the effects he had discovered were not due to electrostatic induction or to ordinary electrodynamic induction (14). He put induction coils in the transmitting and receiving circuits; turning them round altered the induction effects but the 'clicks' of the extra-spark were not altered. Hughes's very delicate musical ear would, no doubt, detect the difference between the spark 'clicks' and the out-of-balance induction noise when the transmitter made no sparks (e.g. the clock-cum-microphone). But he was no doubt wrong in thinking that the signals were transmitted by a kind of conduction in the air—an hypothesis that he stuck to—although he was surprised that signals at a distance could be received through such a high resistance. However, Stokes, a mathematical physicist who had rejected his work with the confidence of those who do not look closely and intimately into nature's ways

(he had rejected papers by Faraday and Maxwell), was wrong also in dismissing it as 'mere phenomena of loose contact'. For Hughes this demonstration in the presence of Stokes was a great misfortune as we can now see; for his great experimental abilities, delicacy of touch and ear as well as persistence would surely have led him much further. He would, for instance, almost certainly have found the value of an antenna in the receiving circuit as well as in the transmitting circuit. Instead he returned to more researches connected with his theory that magnetism was a molecular phenomenon and that the molecules 'arrange themselves so as to satisfy their mutual attractions by the shortest path and thus form a complete closed circuit of attraction'. An external magnetizing force would cause these circuits to break up.

Needless to say, there were disputes over the priority of Hughes's invention of the microphone. He was said to be 'stealing Edison's thunder' and even Sir William Thomson became involved. In a letter to *Nature* defending Hughes, written from the Yacht 'Lalla Rookh', Cowes, he said:

> The beautiful results shown since the beginning of the present year by Mr Hughes with his microphone were described by himself in such a manner as to leave no doubt that he had worked them out quite independently, and that he had not the slightest intention of appropriating any credit due to Mr Edison. It does seem to me that the physical principle used by Edison in his carbon telephone and by Hughes in the microphone is one and the same, and it is the same as that used by M. Clérac, of the 'French Administration des Lignes Telegraphiques' in the 'variable resistance carbon tubes' which he had given to Mr Hughes and others for important practical applications as early as 1866 and that it depends entirely on the fact long ago pointed out by Du Moncel, that increase of pressure between two conductors in contact produces diminution of electric resistance between them' (15).

The salty breezes of Cowes and the traditional supply of warming fluids on yachts may have clouded Kelvin's keen perception in electrical matters, because although he was, of course, correct in saying that the physical principles were the same, i.e. that pressure between two conductors in contact diminishes the resistance between them, there was an important difference in their application. Edison had a diaphragm pressed against a carbon button, thinking apparently that the effect was due to the sound producing a pressure throughout the whole body, whereas Hughes had found far greater sensitivity if the force was extremely light at points of loose contact. In fact his lozenge microphone could be attached to a Bell telephone diaphragm to act as a relay (16).

Anyone who has researched for several years on a new and unresolved problem would hardly expect that Hughes's notebooks would be easily intelligible to others. His notes are certainly very difficult to interpret, not least because suitable words had not been invented. His terms sonometer, microphone, and thermopile, as had been noted, did not mean what they do today. Dates are infrequent and diagrams not always complete. Comments like 'extraordinary' and 'important' sometimes appear—without easily discernible reason. These notebooks were presented by his widow to the British Museum in 1922 and are now bound in leather-covered volumes with gold lettering. It is rather disturbing, however, to find, in one volume, several notebooks bound upside down in the middle of others bound correctly: this inevitably raises doubts as to whether the collection is complete.

The fact that Hughes did not publish the result of his experiments in 'wireless' communication led to his work being overlooked in the popular acclaim that was subsequently given to Hertz, Lodge, and Marconi. There is no doubt that he had succeeded in communicating through free space, but it has been questioned whether he was primarily using the true 'radiation' field of his antenna, or whether it was the induction field that was involved, as Stokes argued. The two fields are equal in strength at a distance of $\lambda/2\pi$ and so the problem arises whether λ, the wavelength, was more than 3000 metres, since the maximum range achieved by Hughes was 500 yards. If he had kept the coil in his circuit, 3000 metres could easily have been the wavelength: but at least in some experiments he omitted it. Moreover, the fact that the signals varied in strength from point to point, being stronger opposite some houses than others, suggests that he was experiencing an interference effect associated with a wavelength substantially less than his maximum range. It therefore appears that Hughes genuinely discovered a method of communication using radio waves, and invented some of the essential components, although he had not unravelled the underlying physics at the time when he discontinued his experiments.

Lodge, like Hughes (but many years later), thought that signals might be detected for half a mile, but saw no practical use for his own discoveries. Hertz was an academic, interested in demonstrating Maxwell's ideas about electromagnetic waves, and was not primarily an inventor or interested in communication. His great achievement was the demonstration that Maxwell's waves were similar to light as regards velocity, reflection, refraction, diffraction and polarization, but this he did not do until 1888. Marconi's important inventions and discoveries were also made many years later. Hughes remained content to witness the re-discovery of many features of his own work without making any claim to priority. At last, after twenty years, and at first refusing

(saying 'it would be unfair to later workers in the same field to spring an unforeseen claimant to the experiments which they have certainly made without any knowledge of my work'), he gave a short account of his discoveries in a letter to J. J. Fahie for publication in his history of wireless telegraphy (17). Writing in 1899, Hughes expressed his admiration for Hertz's and Marconi's experiments and readily admitted their priority in publication, pointing out that Hertz had succeeded although using a detector—a circle of wire with a spark gap—far less sensitive than his own 'sensitive imperfect contact' (as Marconi called it when, later, Lodge had named it a *coherer*.)

In 1880 Hughes was elected to the Royal Society. The citation, after listing the titles already mentioned, to which should be added: Kt of St Maurice and St Lazare, Italy; Kt of St Michael, Bavaria; Commander of the Noble order of Charles III, Spain, states his achievements as follows:

> Inventor of the Printing Telegraph. Discoverer of the Capillary Movement of Mercury under the influence of Electric Currents. Inventor of the Microphone, the Sonometer, and Induction Balance, and other Electrical Appliances. Received the 'Grand Prix' for Telegraphy at the Paris Universal Exhibition of 1867.
> W. G. Adams, W. C. Roberts, William Thomson, F. Guthrie, J. H. Gladstone, W. De La Rue, C. V. Walker.

Hughes's unfortunate experience with the Society's Officers in his rooms in Great Portland Street did not affect his election which took place soon afterwards nor did it prevent him from receiving the Society's Royal Medal in 1885—for the microphone, induction balance, and sonometer—but it seems possible that it had something to do with the fact that he did not receive an obituary notice, in spite of his bequest of £4000. This omission remains a mystery.

Unaffected by his immense fortune, many decorations and medals, Hughes lived quietly in his modest apartments in Great Portland Street: at some later time he appears to have moved to 40 Langham Street, from which address, in 1899, he wrote the first published account of 'a few leading experiments that I made . . .'. His devoted wife who was an American, returned to her own country after his death in 1900. He left half a million pounds: most went to four London hospitals but scientific societies in this country and in France also received considerable bequests, resulting in the establishment of the Hughes Medal of the Royal Society, and the Hughes Scholarship of the Institution of Electrical Engineers.

Those who knew David Hughes wrote of him with affection calling him

the 'most genial of companions, with a keen sense of the ridiculous, thoroughly appreciative of fun in others, and those who were privileged to belong to the little coterie that used to meet at luncheon three times a week, first at the Horseshoe, Tottenham Court Road, afterwards at the Societé National Français, and ultimately at Frascati's Restaurant will record with pride and happy remembrance his genial comradeship, his merry and contagious laugh, his inexhaustible fund of information or story, and simple and lovable disposition (18).

Owing to his disheartened abandonment of his 'wireless' researches and his reluctance to claim any priority for the discoveries and inventions that he had already made, David Hughes missed the distinction of being the founder of the epoch-making developments in radio communication that occurred twenty years afterwards, but he was the first to achieve radio communication by his invention of electrical transmitting and receiving circuits that enabled signals to be heard at a distance without the use of wires.

Notes

(1) 'On the Action of Sonorous Vibrations in varying the Force of Electric Current.' *Proc. R. Soc. Lond.*, **27**, 362 (1878). Reprinted in *Telegr. J.*, **6**, 201 (1878).

(2) Evershed, S. 'The Life and Works of David Hughes.' *J. Instn Elect. Engrs*, 1245 (1931).

(3) *Telegr. J.*, **9**, 124 (1881).

(4) 'The Induction Balance & Sonometer'. *Proc. R. Soc. Lond.*, **29**, 56 (1879).

(5) Cf 'Researches with Professor Hughes's Audiometer' by Benjamin Ward Richardson, M.D., LL.D., F.R.S., *Telegr. J.*, **7**, 212 (1879).

(6) 'Assaying by Induction'. *Telegr. J.*, **7**, 192 (1879).

(7) *Telegr. J.*, **9**, 317 (1881).

(8) Munro, J. 'The Experiments of Prof. Hughes on Ether Telegraphy.' *Electr. Rev.*, **44**, 883 (1899). This article contains drawings and diagrams and is a valuable source of information to which the writer is indebted.

(9) Mr Geddes very kindly displayed some of Hughes's apparatus for the writer to examine. Certainly one felt that if this collection was to be left out on the bench for a night, a note should be left for the cleaners not to throw it away.

(10) When Marconi re-discovered the value of an antenna at the sending station (patented in 1896) it was called 'an epoch in the history of wireless telegraphy'. Poincaré, H. and Vreeland, F. K. *Maxwell's Theory & Wireless Telegraphy*, p. 139, London: Constable (1904).

(11) 'Bound Notebooks', p. 246, Nov. 12. British Library 40161.

(12) 'Bound Notebooks', p. 262, British Library 40161.

(13) Hughes had noticed that his microphones were very sensitive to heat, and that heat enhanced their action. This suggested that perhaps, thermoelectric effects were involved: hence, possibly, the confusing name 'thermopile'.
(14) 'Bound Notebooks', p. 247. British Library 40161.
(15) *Telegr. J.*, **6**, 342 (1878).
(16) Houston, E. J. and Thomas, Elihu. 'The Microphone Relay'. *Telegr. J.*, **6**, 343 (1878).
(17) Fahie, J. J. *History of Wireless Telegraphy*, Edin. & London: Blackwood (1899), p. 290.
(18) 'C.W.C.' *J. Instn. Elect. Engrs.*, **29**, 954 (1900).